Evaluation of the sedimentation levels and cost-efficient depth mapping in Lake Pushmataha

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Abstract

The goal of this project was to analyze the water quality of Lake Pushmataha, located on the Choctaw Indian Reservation in Neshoba County, Mississippi. The Choctaw were interested in continuing construction around the lake and utilizing the lake for recreational fishing. The community is concerned with the water quality of Lake Pushmataha due to extensive construction on the land neighboring its northern shore. An increase in sedimentation and anthropogenic pollutants could result in poor water quality and possibly alter the ecology of the lake. The major purpose of this investigation was to create a visualization of the lake's current runoff and sedimentation levels. NASA missions such as Landsat 7, Aqua, and Shuttle Radar Topography Mission (SRTM) were utilized to collect data in land cover and land usage, vegetation dynamics, and elevation, respectively. Aerial photography, topographical data, precipitation, and soil moisture data were collected from the following non-NASA sources: Mississippi Band of Choctaw Indians, United States Geological Survey (USGS), and the Natural Resources Conservation Service (NRCS). For the visualization, aerial photographs were overlaid with Landsat 7 data and a digital elevation map of the county, provided by the Choctaw tribe, to construct a 3-Dimensional visual in the Earth Resources Data Analysis System (ERDAS). The team used the Automated Geospacial Watershed Assessment (AGWA) tool as a predictive model to meet the concerns of the Choctaw Indians. AGWA has two components, the Soil and Water Assessment Tool (SWAT) and the Kinematic Runoff and Erosion Model (KINEROS2). This particular model is used primarily to reduce the time required to run SWAT and KINEROS2 separately. Watershed elements such as soil, land cover, and precipitation data, along with digital elevation maps, served as model inputs. Model outputs were imported back into AGWA, which then output a 2-Dimensional display. The AGWA tool can only provide qualitative estimates of runoff and erosion, but careful calibration can provide quantitative estimates. Each element of SWAT and KINEROS2 output specific variables: SWAT outputs water yield, sediment yield, transmission loss, surface runoff, percolation, and precipitation. KINEROS2 outputs infiltrations, runoff, peak flow, sediment yield, and sediment discharge. A secondary objective of the project was to determine the feasibility of obtaining a depth map of Lake Pushmataha. The various data inputs and modeling software led to a more comprehensive understanding for the future commercialization potential of the Lake Pushmataha watershed.

Introduction

Since Chief Phillip Martin came into office in 1959, the Choctaw Native Americans have been striving to create a better life for themselves and their community. The construction of the Silver Star Hotel and Casino, along with the Pearl River Resort and Geyser Falls Water Park, have led to the growing economic status of this 9,100-member tribe. Economic success has allowed them to work on projects that will benefit the community in years to come. Currently, the Choctaw tribe is concerned with the newly constructed Lake Pushmataha that is located along the Pearl River in Neshoba County, Mississippi (Choctaw).

Figure 1. Aerial photography of Lake Pushmataha (January 2003); focusing on construction and commercialization on the lake

The increase in construction around the lake area, as seen in ***Figure 1***, is projected to be the leading contributor to this increase in sedimentation. Sedimentation is the deposition of eroded material in waterways and can be a major factor in water quality and the environment. This process can be exceedingly harmful to particular ecosystems, especially lakes; for example, sediments can bring numerous contaminates into the lake, including DDT (a pesticide).

Sedimentation can also cause eutrophication, the process by which high concentrations of sediment initiate algae growth in a water body (Eutrophication). The construction around the lake will over stimulate the growth of algae, which can eventually interfere with the recreational uses of the lake. The growth of algae can also aesthetically degrade the lake, but more importantly, it affects wildlife. The algae cloud water and block sunlight from entering, thus affecting the temperature of the water, causing stress to many organisms. Also, the lack of sunlight causes underwater plants to die, changing the habitat of the fish and other wildlife in the lake. When the algae begin to die, the decomposition will deplete the essential oxygen in the water (Eutrophication).

Sedimentation can have a direct affect on the behavior of fish in the water as well. According to a study of fish in Lake Tanganyika and Lake Victoria in Africa, sedimentation effects aggressiveness, feces, and the diet of the fish (Michel). In sediment-disturbed lakes, fish become more aggressive due to the lack of available habitats. Sedimentation limits space where fish can live, causing more competition for territory. More time is then spent on swimming and competition than feeding. With less feeding, the amount of organic materials found in the feces of the fish was considerably less than in water of better quality. This imbalance of chemicals is unhealthy for both fish and the general water quality. Also, it was determined in this study that food was of a higher quality in sites with less sediment (Michel). In order to insure that the recreational is sufficient, careful monitoring of the fish and sedimentation must be carried out.

There are a number of approaches to sediment monitoring. Recently, inquiries into using remote sensing tools to monitor water quality have been tested, but normally bed-loads, sleds, and spuds are utilized, as well as water sampling. Bed-loads, commonly used in streams, lie on the bottom of the water body and collect material moving at the bottom of the lake (How). Sleds run along the bottom of the lake, and collect sediment samples. A spud is a cylindrical device dredged into the water and sediment floor. Cups along the side of the spud pull up samples from each layer of sediment. These devices prove to be valuable methods of measuring water quality in Lake Pushmataha.

Sedimentation and other pollutants can cause a variety of effects to the quality of water in Lake Pushmataha. Water tests are taken regularly along the lake to monitor its quality. These tests include measurements of biological oxygen demand, alkalinity, total and free chlorine, dissolved and suspended solids, fecal coliforms, salinity, turbidity, battery, dissolved oxygen, temperature, water depth, conductivity, and pH. The group compared the findings to EPA standards found in the State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Costal Waters guidelines, which were approved June 27, 2003. ***Figures 2-5*** show how some of Lake Pushmataha's readings compare to the EPA standards (readings taken in May and June of 2004).

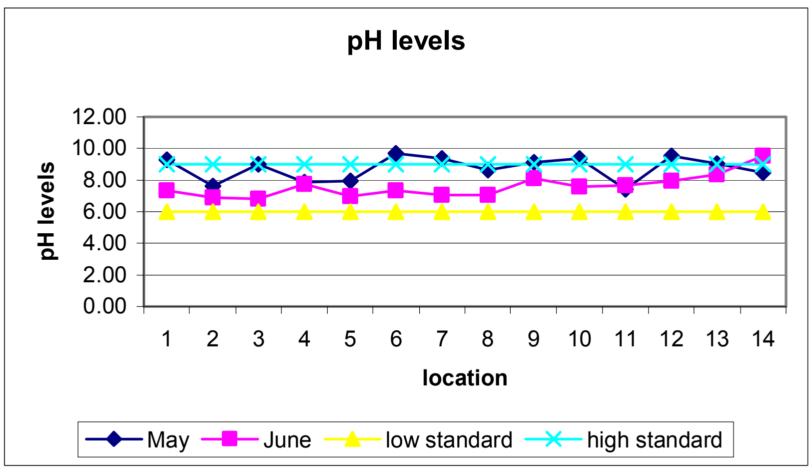

Figure 2. Shows pH levels taken at 14 different locations along the lake

A pH range of 6.0 to 9.0 provides protection for the life of freshwater fish and bottom dwelling invertebrates. These pH levels are tolerable for most fish and have proven to be the best range for them to lay their eggs without being deformed when they are hatched. It is unlikely that fish can survive in water with levels under 6.00 and over 9.00 (EPA).

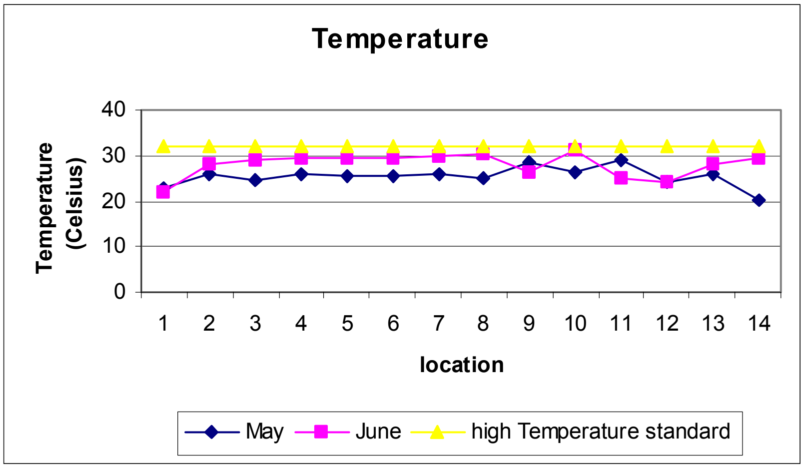

Figure 3. Shows temperature taken at 14 different locations along the lake

The temperature in water affects the availability of food sources in the water as well as the respiration rate for fish and other organisms in the environment. ***Figure 3*** shows that Lake Pushmataha's temperature readings do not exceed maximum EPA standards.

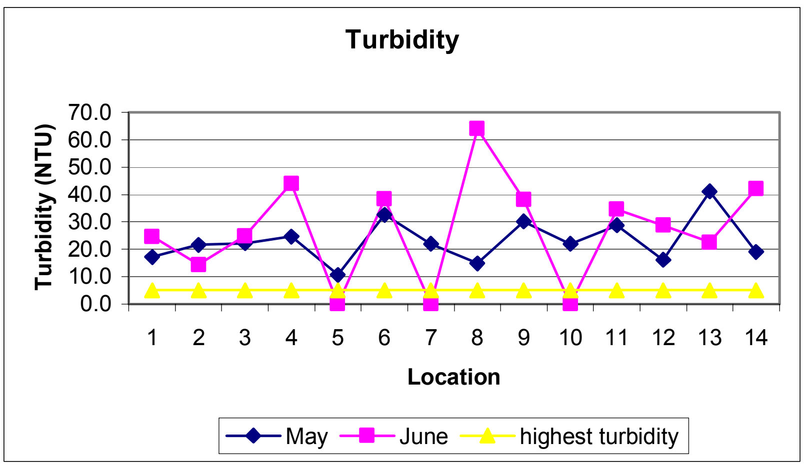

Figure 4. Shows the turbidity at 14 different locations along the lake

Turbidity is a measure of the degree to which light is scattered by suspended particulate material and soluble colored compounds in the water. It provides an estimate of the muddiness or cloudiness of the water due to clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton, and microscopic organisms. As shown in ***Figure 4***, turbidity levels in the lake are far above maximum EPA standards.

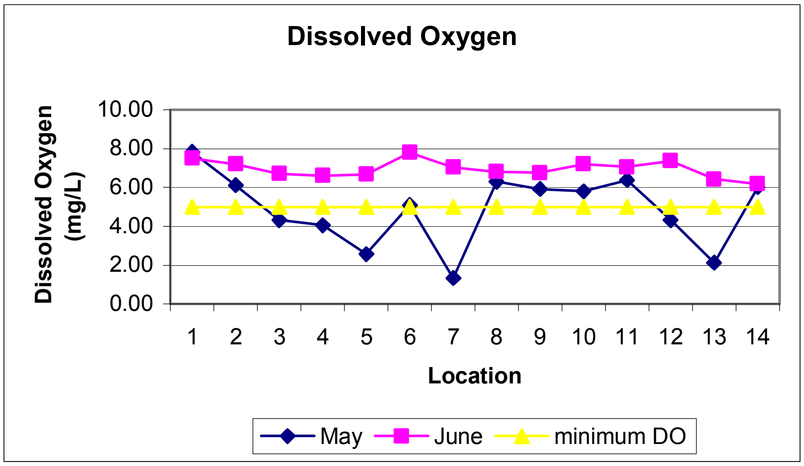

Figure 5. Shows the dissolved oxygen at 14 different locations

The concentration of free (or not chemically combined) gaseous molecular oxygen dissolved in water is usually expressed in milligrams per liter, parts per million, or percent of saturation. Adequate concentrations of dissolved oxygen are necessary for the life of fish and other aquatic organisms as well as the prevention of offensive odors. Dissolved Oxygen levels are the most important and commonly employed measurement of water quality. They indicate a water body's ability to support desirable aquatic life. Levels above 5 milligrams per liter (mg O_2/L) are considered optimal and most fish cannot survive for prolonged periods at levels below 3 mg O_2/L. ***Figure 5*** illustrates that during the month of May, Lake Pushmataha's dissolved oxygen levels frequently dropped below minimum EPA standards. By June, however, levels remained above the minimum and safe for aquatic life.

As shown, an increase in sedimentation could have many different effects on the lake. The readings demonstrate how surrounding construction and commercial sites have affected the lake in May and June of 2004.

Project Approach

The Mississippi Water Management team researched available NASA and non-NASA tools applicable to the objectives of the Choctaw tribe. Through continued contact with the Mississippi Band of Choctaw Indians and NASA Stennis Space Center, the team was able to acquire aerial photographs and contaminant readings of Lake Pushmataha. Photographs, taken over time, show a gradual increase in sediment. The Choctaw conduct their own contaminant readings along the lake, which was provided to the team. The information included water quality, for types of sedimentation in the lake, and other ecological findings. This information allowed the team to clearly understand the concern of the Choctaw tribe.

Data from the three NASA missions Landsat 7, Aqua, and SRTM were collected. The Landsat 7 mission, launched April 15, 1999, incorporates the Enhanced Thematic Mapper (ETM+) instrument (Somers). Specifically, the ETM+ instrument is an eight band multispectral scanning radiometer capable of providing high resolution imaging of the Earth's surface. ETM+ detects spectrally filtered radiation at visible, near infrared (NIR), short-wave, and thermal infrared (TIR) frequency bands (Somers). For this project, the instrument was used to collect geophysical parameters in land cover and land usage in the form of both radiometric and geometric corrections.

The Moderate Resolution Imaging Spectroradiometer, or MODIS instrument aboard the Aqua mission (launched May 4, 2002) was used by the team to collect data pertaining to vegetation indices

(Somers). Aqua is specifically designed to acquire precise atmospheric and oceanic measurements to provide a greater understanding of their role in the Earth's climate and its variations. The satellite's instruments provide regional to global land cover, land cover change, and atmospheric constituents (Somers). In this project, the collected data were gathered in the form of images depicting a more detailed outline of watershed and its vegetation cover.

Elevation data was collected from the Shuttle Radar Topography Mission (SRTM). Launched February 11 of 2000, the goal of the SRTM mission was to map the world in three dimensions (Somers). However, because the lake was constructed in 2002, the satellite could not display the current elevation of the lake area. The team resorted to using SRTM data from 2000, Landsat 7 images, and aerial photography from January of 2003 in order to make a 3-D view of Lake Pushmataha using ERDAS, seen in ***Figure 6***.

Figure 6. 3-D visual created through ERDAS of Lake Pushmataha

The utilization of ERDAS allowed the Mississippi Water Management team to address the concern of analyzing the water quality in Lake Pushmataha by providing a 3-Dimensional image of the lake that can show where runoff and increased sedimentation will occur.

Non-NASA resources were used to gather a variety of data as well. The team collected water quality standards from the Environmental Protection Agency (EPA), topographical data from the United States Geological Survey (USGS), and soil moisture and precipitation data from the Natural Resource Conservation Service (NRCS).

The data collected from NASA and non-NASA resources served as inputs into the NASA and the United States Department of Agriculture (USDA) partnership model, the Automated Geospatial Watershed Assessment tool (AGWA), which is two models combined together: Soil and Water Assessment Tool (SWAT) and Kinematic Runoff and Erosion Model (KINEROS2).

In this case, the team used KINEROS2 as a model component of the AGWA tool mentioned in the introduction. KINEROS2 provided a qualitative modeling approach to the watershed region of Neshoba County. When the land cover, soil, and elevation data were compiled and layered into the model, the KINEROS2 precipitation file was written. This step lends itself to many assumptions because there are limited number of storm files already created for use in the program. The AGWA model only provides three west coast United States storms to input into the KINEROS2 model, all of which have varying frequencies and durations. The frequencies range from an occurrence of every 2 years to every 100 years, and the durations last from 0.5 hours to 24 hours. With these given parameters, the team compiled a typical storm output using a Santa Barbara storm occurring every two years for a one-hour period. The results showed that Lake Pushmataha's watershed is affected minimally by natural sedimentation and runoff. ***Figure 7*** shows one of the resulting visuals acquired. Lake Pushmataha and the Neshoba county watershed areas are represented as the green rectangle in the model, which highlights portions in varying peak flow in cubic meters per second.

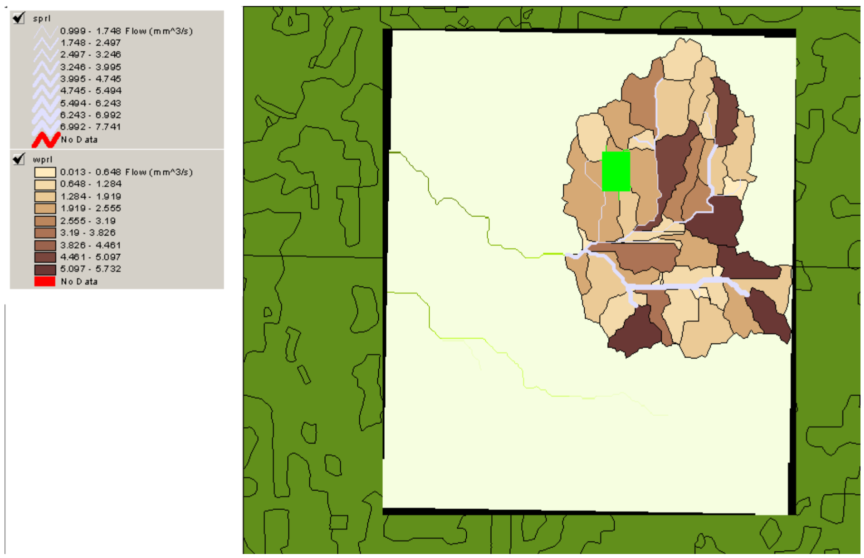

Figure 7. KINEROS2 peak flow output with typical storm input

Figure 7 shows a qualitative model and the outputs gained thus far are merely used for comparison and evaluation purposes of the lake area. In order to more accurately portray the sedimentation and run off values that effect the region, the precipitation files of Neshoba County would have to be used as inputs into the KINEROS2 custom design storm feature provided in the model.

For comparison purposes, another trial was conducted, but a "worst case" scenario storm was used from the given AGWA storms. A Santa Barbara storm that occurs every one hundred years and lasts twenty-four hours was used for this evaluation. The output from this particular storm can be seen in ***Figure 8*** and can be used to compare the peak flow output with the typical storm input. The peak flows shown in ***Figure 8*** are significantly larger than those shown in ***Figure 7***.

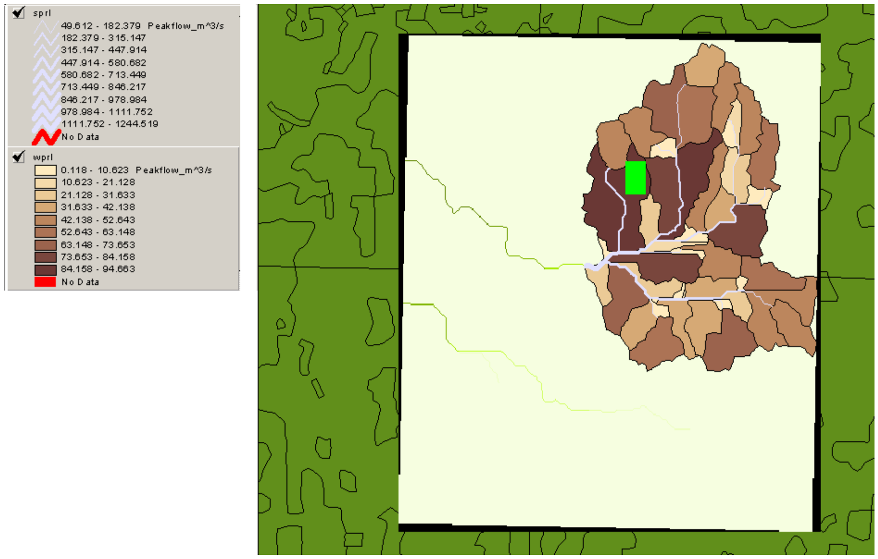

Figure 8. Worst-case scenario storm used for comparison purposes

The team researched methods in creating a depth map of Lake Pushmataha, as well as a method of identifying objects and ecosystems on the bottom of the lake in order to address the second research objective of the Mississippi Band of Choctaw Indians. One NASA source that will be helpful in determining lake depth would be the Aqua mission launched May 4, 2002. The Clouds and the Earth's Radiant Energy System (CERES) instrument on Aqua would be able to gain measurements in radiative energy flux (Somers). By using concepts from heat transfer, similar to Fourier's law of conduction, the depth of the lake can be determined theoretically. Fourier's law is illustrated in ***Figure 9***, and arises from the assumption of constant thermal conductivity or heat transfer coefficient for the entire lake. In order to use Fourier's law in this situation, a thermal scan of the area is needed to find the temperature gradient values. By overlaying the radiative energy flux values, it is then possible to determine the depth of the water at a particular point.

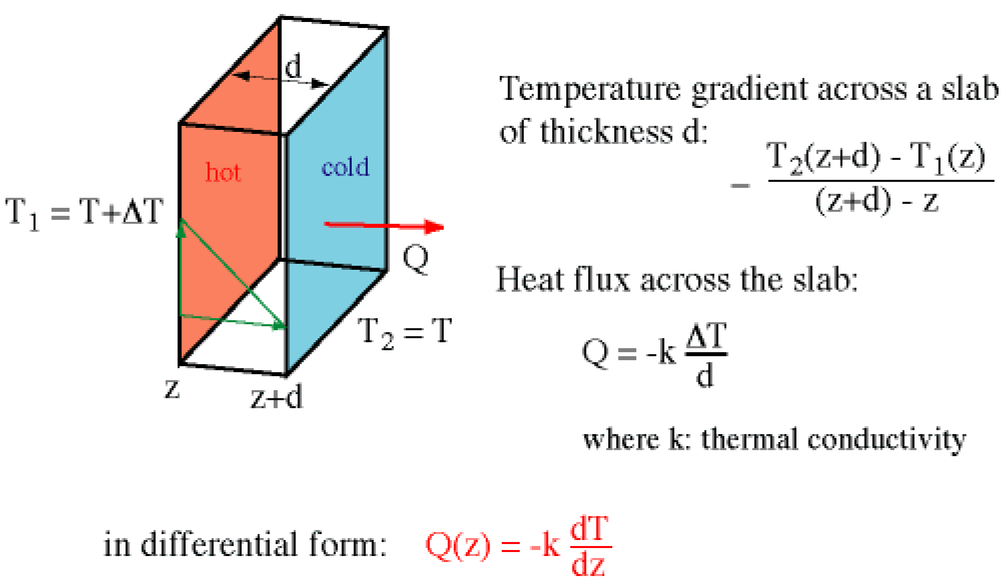

Figure 9. Diagram illustrating Fourier's Law of conduction (http://www.rses.anu.edu.au/~uli/Teaching/Heat/FouriersLaw.html)

One limitation of using this method is the small size of the lake (285 acres). It is difficult to collect accurate temperature readings of the lake in order to compile the measurements required for analysis.

Non-NASA operations, such as Optech and AquaScan, are compliant in addressing the Choctaw concerns. Research on flood areas in the Northeastern Unites States introduced the group to information on hydrographic LiDAR, or Light Detecting And Ranging. Optech, who manufactures laser-based range mapping and detection systems, has a Scanning Hydrographic Operational Airborne LiDAR Survey (SHOALS) instrument, which is the newest hydrographic airborne LiDAR instrument. It employs the same method as sonar, but uses light instead of sound. SHOALS can survey clear waters at depths of 0 to 50 meters, and it is able to map shallow water, shorelines, and topography simultaneously. SHOALS can also identify underwater objects as small as 8 cubic meters resting on the bottom of water body (SHOALS). Currently there is only one SHOALS instrument in use by the U.S. Corps of Engineers. Optech manufactures the equipment, but does not collect the data that the Mississippi Band of Choctaw Indians need. However, contact with the Joint Airborne LiDAR Bathymetry Technical Center of Expertise could provide help to the Choctaw.

AquaScan, another approach, combines Ground Penetrating Radar (GPR) and sonar to profile the water depth and sedimentation levels for lakes and rivers. Radar is effective in waters 0 to 10 feet depth and preferred in shallow waterways and lakes. These measurements can be converted into 3-Deminsional models of the lake (AquaScan). Sonar is more commonly used to survey lakes, but LiDAR can survey a larger area in a faster amount of time.

A NASA mission can be used to determine water clarity. The ETM+ instrument on the Landsat 7 mission measures radiation off the surface of water on lakes (Somers). This method does not produce a depth reading, but can provide insight into water clarity, and thusly, water quality.

NASA has been using the data from the commercial satellite Ikonos to obtain information pertaining to water quality on coastlines and coral reefs. The Ikonos has a 1-meter and 4-meter resolution, which is able to provide data to monitor lakes as small as one acre. This method has been used to monitor lake clarity in Wisconsin, Minnesota, and Michigan (Extending).

Results and Conclusion

This project was initiated by the DEVELOP program and it has been researched for the past ten weeks. Although much research was completed by the current Mississippi Water Management team, future efforts will be needed to address the concerns of the Mississippi Band of Choctaw Indians. Research tasks completed included: research into hydrographic LiDAR and other more common methods, investigation of the AGWA model and the KINEROS2 portion of the model. Hopefully the research into hydrographic LiDAR will help NASA into expanding their investigation into LiDAR, and in turn expanding its strengths in applying their missions to Earth science.

Numerous advances were made in running the AGWA model. The team was able to complete the KINEROS2 portion of the model, from which sediment yield, runoff, and peak flow can be predicted for the watershed area. When the lake is overlaid with the KINEROS2 outputs, another more accurate predictive model of the lake's sedimentation can be made. When a particular area of interest in the watershed regional map is researched and documented, a qualitative approximation of the outputs gained from the model can then be used as a predictive model. In order to create the most accurate predictive visual for this area, a custom Mississippi storm file, rather than one from another part of the country, is recommended for use in running the model.

Due to the complexity of the AGWA model and the short amount of time spent on this project, the SWAT model was not run and the lake has not been layered into the outputs of the KINEROS2. This task will need to be completed by a future team. As the current team completed their portion of the project, they left troubleshooting guides as well as other helpful information for successfully running models.

In the middle of the project's time cycle, aerial photography and digital elevation maps of the lake region were received and compiled to create a 3-Dimensional visual using ERDAS. A virtual 3-Dimensional flyby of the lake area was created using available data. Future teams will need to obtain more recent aerial photographs in order to create a more accurate representation of the lake area.

The team made a very valuable contact with National Sedimentation Laboratory in Oxford, Mississippi who could assist with the project as it continues. This contact, has a significant background in sedimentation research, and may be useful in providing ecological expertise. Additionally, the contact person expressed interest in conducting on-site sedimentation research and may provide other helpful contacts in the technical modeling aspect for future project completion.

This project will be used by the Mississippi Band of Choctaw Indians as a tool to evaluate their construction plans for the area around the lake. If their concerns about sedimentation are not alleviated, then they will have to reduce their future goals for expansion. A loss of economic revenue from future construction will not only affect the economic stability of the Choctaw tribe, but the surrounding communities as well.

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